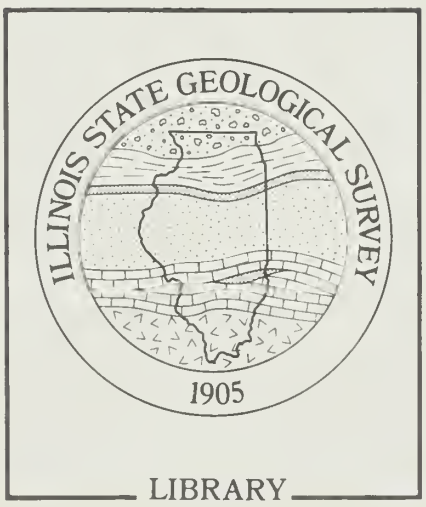
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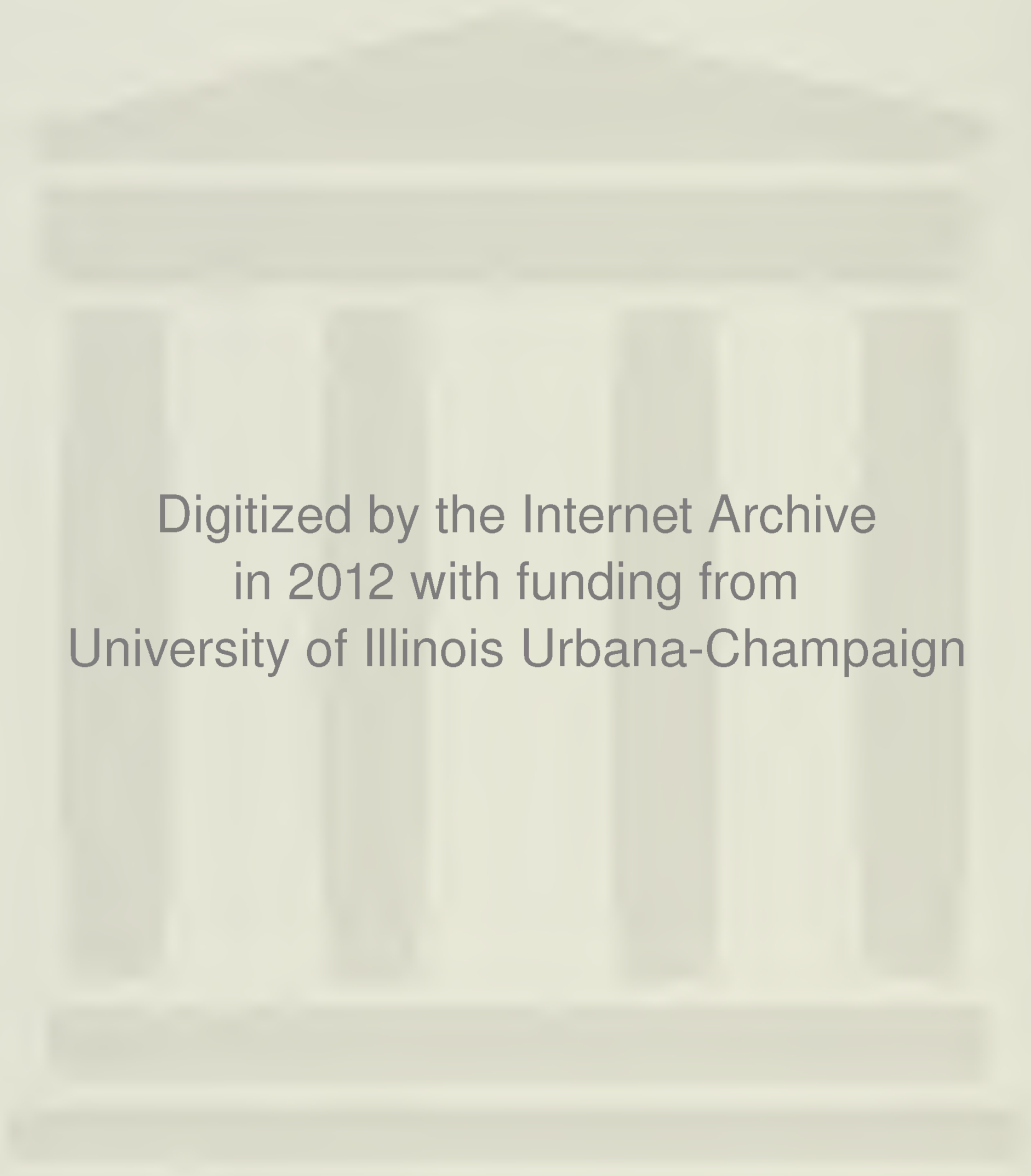
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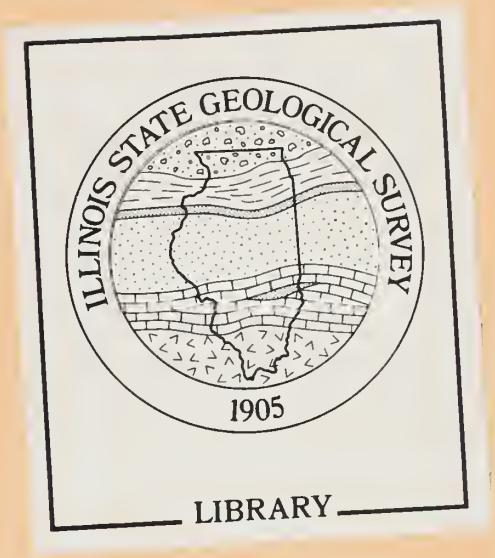

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ABSTRACT
The historical record of earthquakes having epicenters in Illinois extends over 193 years and includes 180 earthquakes. Of the historical Illinois earthquakes, 81.1 percent had epicenters south of latitude 39.1°N, where zones of crustal weakness are most prevalent. The cumulative amount of energy released during Illinois earthquakes is relatively small; far more energy was released during the catastrophic earthquakes of 1811 and 1812 in the New Madrid Seismic Zone immediately south of Illinois. Most historical earthquakes originating in Illinois have caused only moderate damage; none has had a maximum intensity value as great as VIII on the Modified Mercalli Intensity Scale (MMIS). The greatest seismic risk in Illinois, especially in southern Illinois, is from large earthquakes that may originate in the New Madrid Seismic Zone.

THE HISTORICAL RECORD

The historical record of *earthquakes* having epicenters in Illinois begins on January 8, 1795 (appendix A). On that date an earthquake having a maximum *intensity* value of V on the Modified Mercalli Intensity Scale (MMIS) (Wood and Neumann, 1931) (table 1) occurred near Fort Kaskaskia on the Mississippi River in southwestern Illinois (Stover et al., 1979a). As of October 5, 1988, when this report was written, the historical record of Illinois earthquakes included 180 earthquakes having MMIS maximum intensity values ranging from II to VII. During the 193 years spanned by the historical record, no earthquake with an epicenter in Illinois has had an MMIS maximum intensity value as great as VIII. Earthquakes with maximum intensity values equal to or greater than VIII are generally associated with serious damage to well-built, man-made structures.

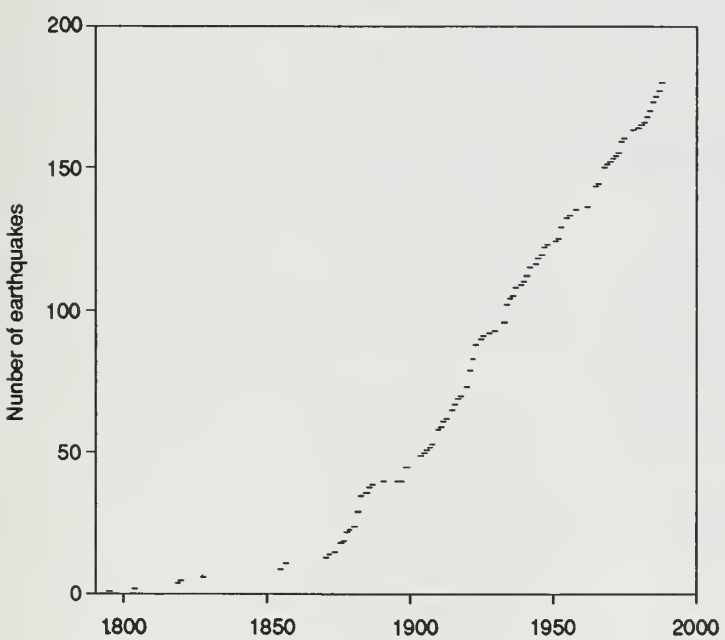

Figure 1 Cumulative number of earthquakes recorded in Illinois.

Further examination of the Illinois record indicates that the number of historical earthquakes increased noticeably around the year 1870, probably reflecting more consistent record-keeping after 1870 rather than an increase in seismic activity. Since that time the rate at which earthquakes have been recorded (figure 1) has remained nearly constant.

The record of Illinois earthquakes occurring before the late 1800s consists primarily of newspaper accounts, along with some letters, diary entries, and other personal accounts.

Table 1 Modified Mercalli Intensity Scale of 1931.*

Scale degree	Effects on persons	Effects on structures	Other effects	Rossi-Forel equivalent	Equivalent body-wave magnitude
I	Not felt except by few under favorable circumstances.			I	
II	Felt by few at rest.		Delicately suspended objects swing.	I-II	2.75
III	Felt noticeably indoors. Standing cars may rock.		Duration estimated.	III	
IV	Felt generally indoors. People awakened.		Cars rocked. Windows rattled.	IV-V	3.75
V	Felt generally.	Some plaster falls.	Dishes, windows broken. Pendulum clocks stop.	V-VI	
VI	Felt by all. Many frightened.	Chimneys, plaster damaged.	Furniture moved. Objects upset.	VI-VII	4.75
VII	Everyone runs outdoors. Felt in moving cars.	Moderate damage.		VIII	
VIII	General alarm.	Very destructive and general damage to weak structures. Little damage to well built structures.	Monuments, walls down. Furniture overturned. Sand and mud ejected. Changes in well-water levels.	VIII-IX	5.75
IX	Panic.	Total destruction of weak structures. Considerable damage to well built structures.	Foundations damaged. Underground pipes broken. Ground fissured and cracked.	IX	
X	Panic.	Masonry and frame structures commonly destroyed. Only best buildings survive. Foundations ruined.	Ground badly cracked. Rails bent. Water slopped over banks.	X	6.75
XI	Panic.	Few buildings survive.	Broad fissures. Fault scarps. Underground pipes out of service.	X	
XII	Panic.	Total destruction.	Acceleration exceeds gravity. Waves seen in ground. Lines of sight and level distorted. Objects thrown in air.	X	7.75

*After Wood and Neumann, 1931; Nuttli and Herrman, 1978.

Systematic record-keeping began during the last quarter of the 19th century when federal government agencies such as the U.S. Weather Bureau, the U.S. Coast and Geodetic Survey, and the U.S. Geological Survey began to publish annual lists of *felt earthquakes* with intensities of III or more on the MMIS (Nuttli and Herrmann, 1978).

The first Wiechert *seismograph* was installed at Saint Louis University in 1909—but not until the early 1960s was the World-Wide Standard Seismograph Network established. Obviously, the historical record of Illinois earthquakes is incomplete for the years before the advent of the seismograph in the midcontinent. Many Illinois earthquakes having small maximum intensity values (especially those occurring in sparsely populated rural areas) were not recorded.

In this report, our analyses of recorded Illinois earthquakes are based on maximum intensity values rather than on magnitude values, because only a few magnitude values are included in the historical record before 1960. The record after 1960 includes several earthquakes for which magnitude determinations, but no corresponding maximum intensity values, were given. In these cases appropriate maximum intensity values were assigned according to the following relationship (Nuttli and Herrmann, 1978) for earthquakes in the central United States:

$$I_{max} = 2m_b - 3.5 \quad (1)$$

where I_{max} is maximum intensity on the Modified Mercalli Intensity Scale and
m_b is body-wave magnitude.

LOCATIONS AND FOCAL DEPTHS OF ILLINOIS EARTHQUAKES

Little information exists on the focal depths (the depths at which the initial earthquake ruptures began) of recorded Illinois earthquakes; no focal depths appear in the records before 1960. Available data on the focal depths of Illinois earthquakes (appendix A) tend to support Herrmann (1979), who concluded that focal depths of earthquakes in the central United States fall into the shallow category (0 to 70 km; 0 to 45 miles) and generally lie in the upper 20 km (12 miles) of the earth's *crust*.

Most of the historical Illinois earthquakes have occurred in southern Illinois: 81.1 percent have epicenters south of latitude 39.1°N (figures 2 and 3). The rest (18.9 percent) have epicenters north of latitude 39.9°N. No historical earthquakes have occurred in a band approximately 70 miles wide extending across the entire central part of the state (figure 2). The fact that most of these earthquakes have occurred in the southern part of the state is to be expected, since known *faults* and *zones of weakness* in the earth's crust are also most numerous there (Nelson, in press) (figure 4). However, it is difficult to detect epicentral trends that are related to known structures because the record contains such a small number of earthquakes. Perhaps such relationships could be detected if a seismograph network capable of recording numerous small seismic events were established in the region. A seismograph network set up in the New Madrid Seismic Region (Stauder et al., 1976; Stauder, 1982) has been very successful in this respect.

Focal mechanisms (the orientation of the fault plane and the shearing forces at the place where the earthquake rupture begins) have been determined for only a few earthquakes in southern Illinois. Relating these focal mechanisms to known structures has been difficult. Consider, for example, the November 9, 1968, earthquake epicentered near Broughton in Hamilton County, Illinois. This earthquake had a body-wave magnitude of 5.5 and an MMIS

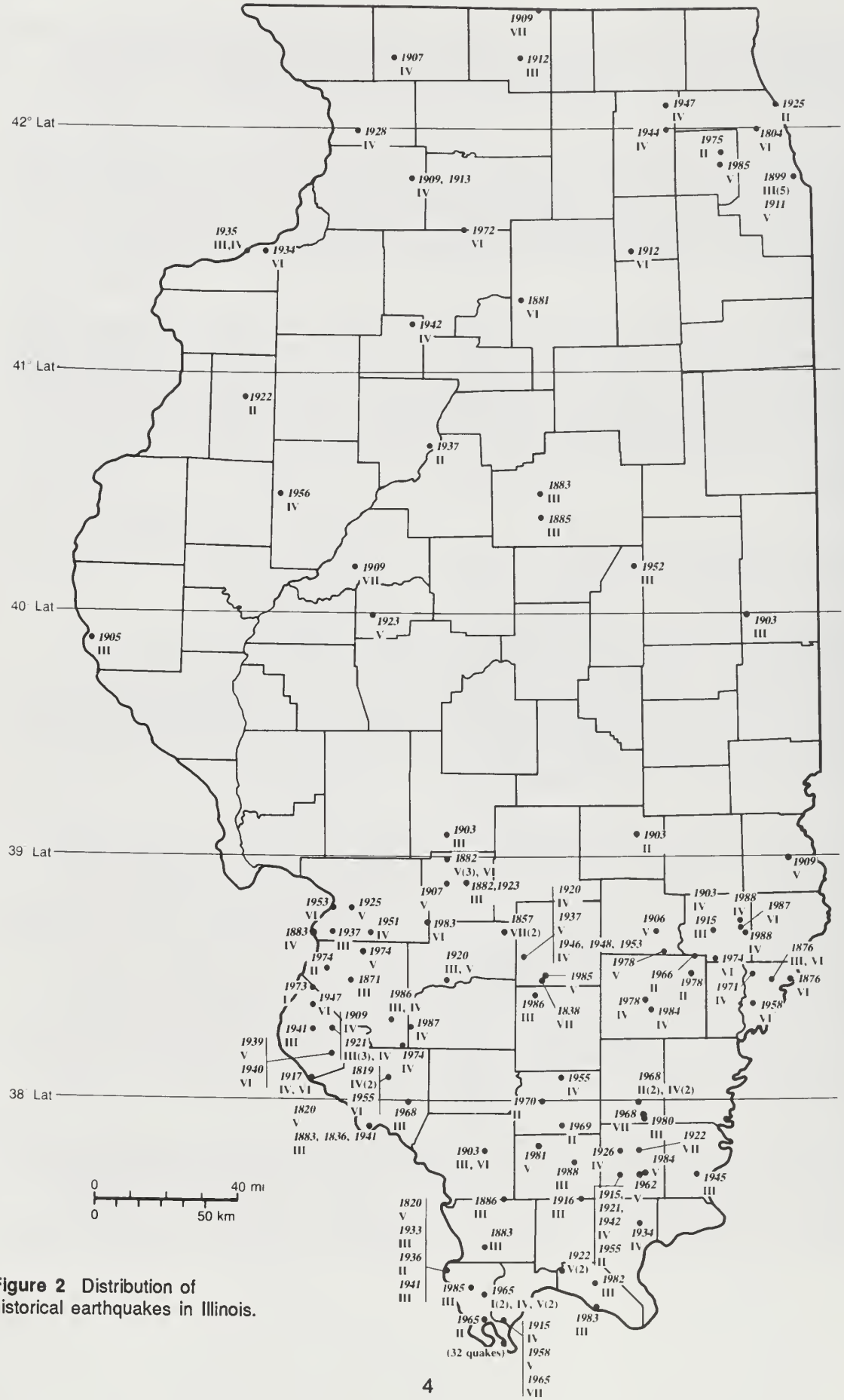

Figure 2 Distribution of historical earthquakes in Illinois.

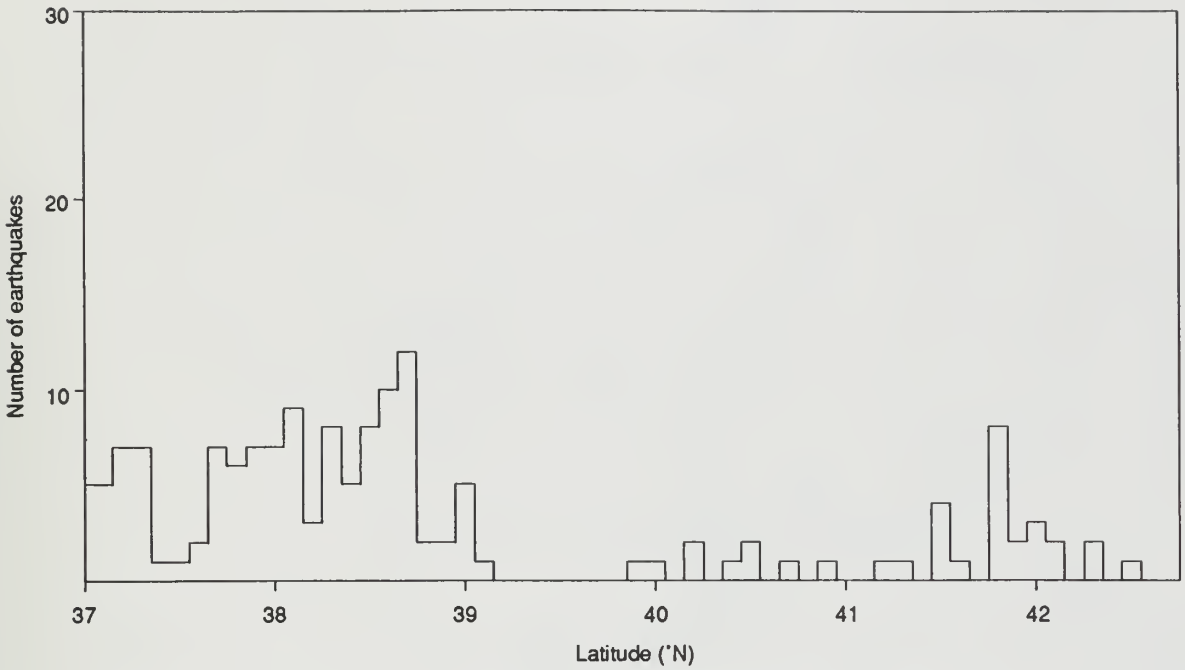

Figure 3 Histogram showing distribution of historical Illinois earthquakes by latitude.

maximum intensity value of VII. Its focal depth was determined to be 19 km (12 miles) (Gordon et al., 1970). The focal mechanism solution for this quake showed reverse faulting, with one *nodal plane* striking N15°E and dipping 45° to the west and the other striking N01°W and dipping 47° to the east (Stauder and Nuttli, 1970). Stauder and Nuttli indicated that a relationship may exist between this earthquake and the Wabash Valley Fault System (WVFS) to the east. However, the faulting in the WVFS is predominantly high-angle normal and reverse faulting. If, in fact, the November 9, 1968, earthquake is related to the WVFS, then some of the observed faults may be *listric* near the focal depth—that is, the fracture may curve upward, first gently and then more steeply, from a horizontal position.

The focal mechanisms determined for this and other more recent earthquakes in southern Illinois are consistent with the regional stress pattern in the midcontinent—east-west compression (Zoback and Zoback, 1981; Nelson and Bauer, 1987). The focal mechanism of a June 10, 1987, earthquake epicentered near Claremont in Richland County, Illinois (appendix A), is *strike-slip* with a small amount of *dip-slip*. The nodal planes are N36°E with a dip of 85° to the southeast and N54°W with a dip of 60° to the southwest. This focal mechanism is very similar to that of the April 3, 1974, earthquake, epicentered approximately 15 km (9 miles) south-southwest (appendix A) (Taylor and Herrmann, 1987).

Nuttli (1973a) categorized parts of Illinois into four discrete seismic regions where damaging earthquakes are most likely to occur: the New Madrid Faulted Zone, the Wabash Valley Faulted Zone, the Ste. Genevieve Faulted Zone, and the North-Central Illinois Seismic Region (figure 5). He then assigned design earthquakes to the regions (a design earthquake is the largest-magnitude earthquake expected to occur in a given region). The assigned design earthquakes for the regions have body-wave magnitudes of 7.2, 6.2, 6.2., and 5.7, respectively.

STRAIN ENERGY RELEASE

To provide another perspective on Illinois seismicity, we applied the concept of *strain energy release* to historical Illinois earthquakes. Using the relationship between MMIS maximum intensity and body-wave magnitude for earthquakes in the central United States (Nuttli and

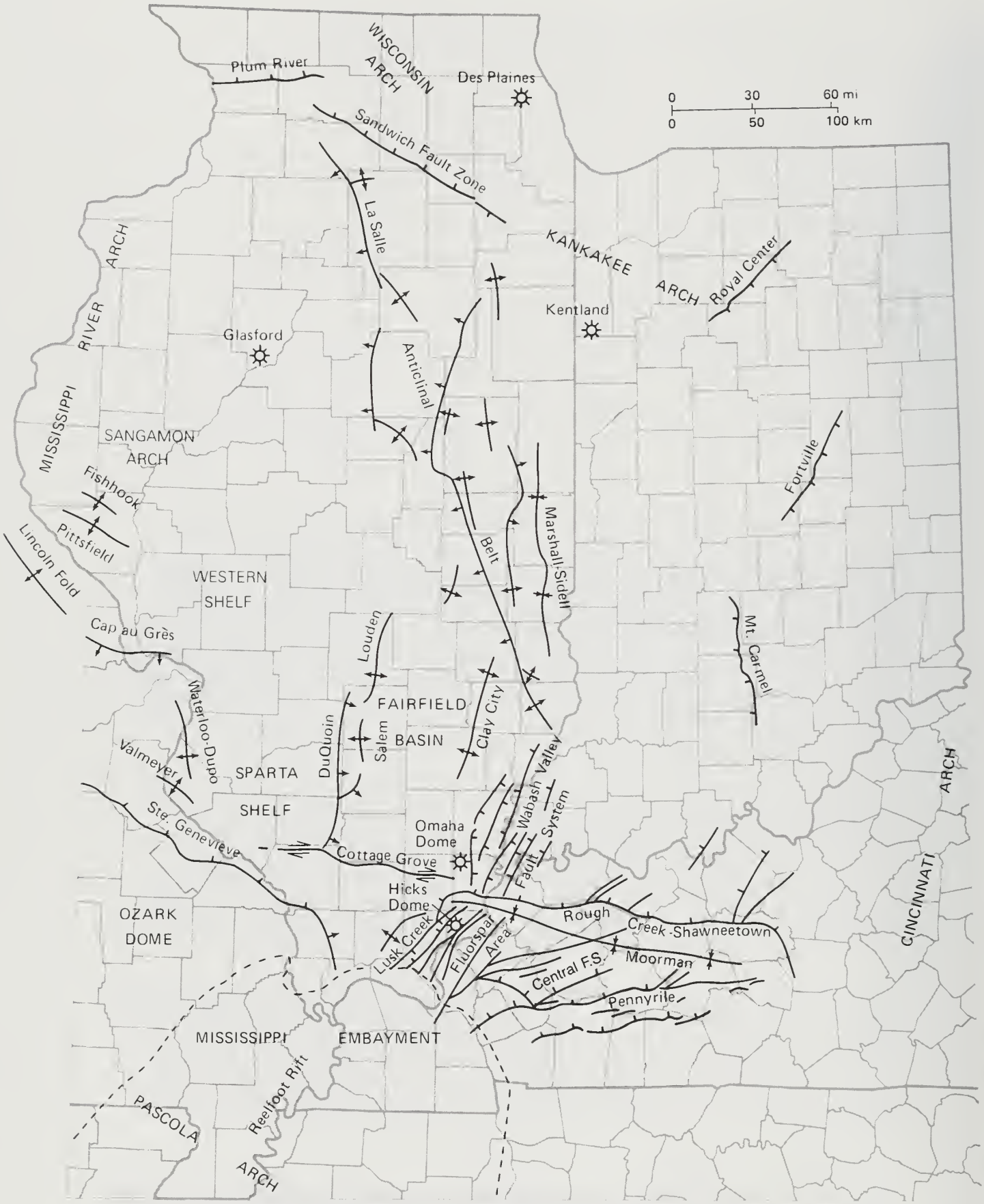

Figure 4 Structural features in Illinois and vicinity (Nelson, 1990).

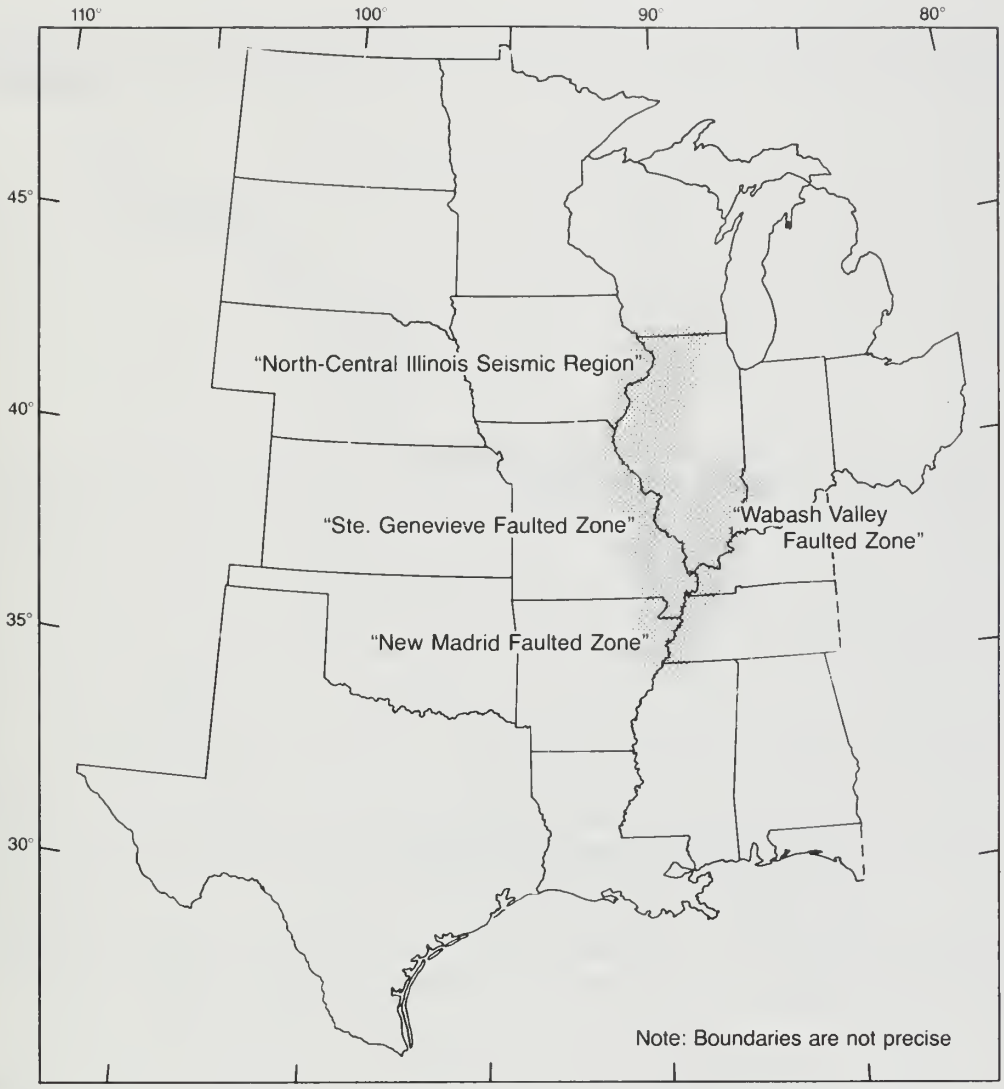

Figure 5 Approximate boundaries of seismic regions in the central United States (modified from Nuttli, 1973a).

Herrmann, 1978) (Equation 1), together with a relationship between body-wave magnitude and strain energy released in an earthquake (Gutenberg and Richter, 1955),

$$E = 10^{5.8 + 2.4\, m_b} \quad (2)$$

where E is strain energy in ergs;
m_b is body-wave magnitude,

we calculated the yearly amounts of strain energy released in historical earthquakes. Then we used these calculated values to construct a graph of cumulative strain energy released between the years 1795 and 1988 (figure 6).

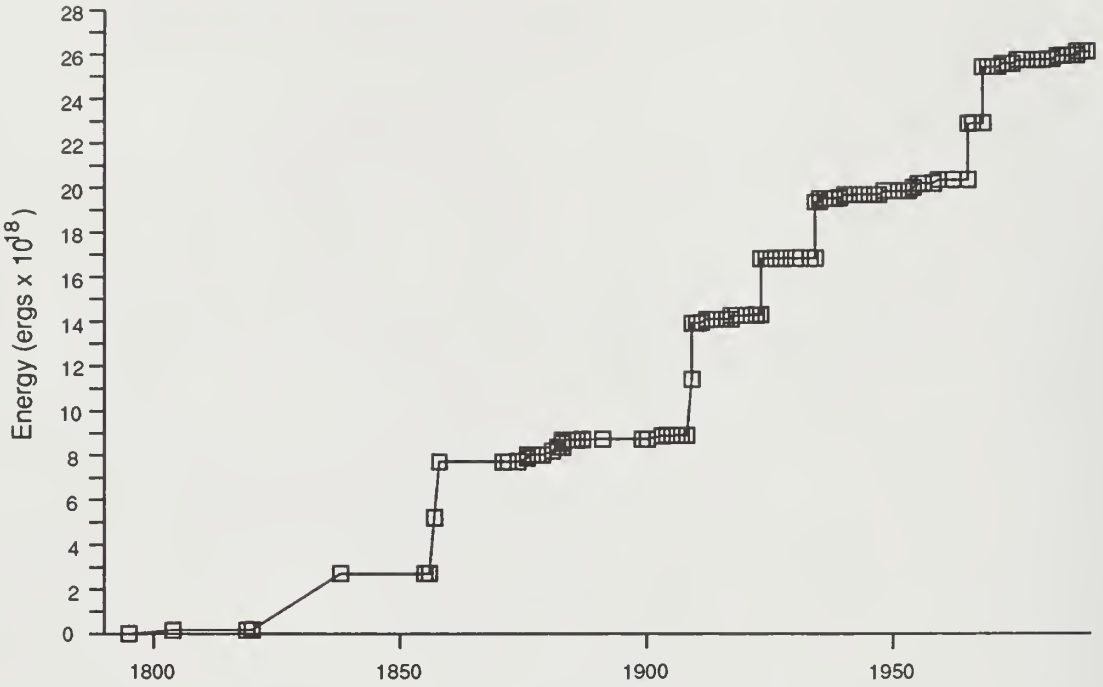

Figure 6 Cumulative strain energy released by historical earthquakes in Illinois.

The total amount of strain energy released in historical Illinois earthquakes is approximately 2.61×10^{19} ergs. To put this amount of energy in proper perspective, consider first the smallest of the three catastrophic earthquakes that occurred in the New Madrid Seismic Zone during the winter of 1811-1812. This earthquake was assigned a body-wave magnitude of 7.1 (Nuttli, 1973b). The energy associated with an earthquake of this magnitude (6.92×10^{22} ergs) is approximately 2.65×10^{3} times the total amount of energy released in all historical Illinois earthquakes. An earthquake having a MMIS maximum intensity value of VIII (the lowest intensity value associated with serious damage to well-constructed buildings) would radiate about 3.98×10^{19} ergs—about 1.52 times the total amount of energy released in all historical Illinois earthquakes. The official figure for the energy released by a nominal atomic bomb of the Hiroshima type—8.0×10^{20} ergs (Richter, 1958)—is about 30.65 times the total amount of energy released in all historical Illinois earthquakes.

The rate at which strain energy has been released in historical earthquakes in Illinois is, in general, low and constant (figure 6). Most of the strain energy from these earthquakes has been released during the less frequent quakes of high maximum intensity.

RECURRENCE PERIODS

Architects, construction engineers, insurance company actuaries, and others are interested in data on *recurrence periods*. The current method of determining recurrence periods, which involves statistical analyses of historical earthquake data, assumes that the geologic processes resulting in earthquakes are in *steady state* and that uniform seismicity exists over the area in question (Nuttli, 1974). Considering the brevity (geologically speaking) of the record of Illinois earthquakes, we can reasonably conclude that the prevailing regional stresses in Illinois have been in place for at least the 193 years covered by the Illinois record. According to Irving (1977), the current stress field dates back no more than 70 million years.

We constructed a histogram showing the MMIS maximum intensity (I_{max}) distribution of all historical Illinois earthquakes (figure 7) and used this histogram as the basis for calculations

Maximum intensity	Recurrence period (yrs)
III	2.23*
IV	3.83
V	6.60
VI	11.35
VII	19.51
VIII	33.56*

* Extrapolated values

of recurrence periods (see above). Although the vast majority of historical earthquakes have occurred in the southern part of the state, examination of the maximum intensities of earthquakes in both northern and southern Illinois indicates that these distributions are proportionally similar. Many earthquakes with MMIS maximum intensity values of III or less have occurred over the past 193 years but are not in the historical record; therefore we devised a method of calculating recurrence periods that was based primarily on historical earthquakes having MMIS maximum intensity values from IV to VII. We determined a least-squares exponential function for that part of the histogram (figure 8) dealing with historic Illinois quakes rated III or greater on the MMIS. This theoretical function fitted the observed data extremely well (r = -0.98739) over the range of maximum intensity between IV and VII, and thus the least-squares exponential function appeared to be a good representation of the maximum intensity distribution of historical Illinois earthquakes. As expected, however, the value provided by the theoretical function for the number of earthquakes with MMIS maximum intensity III was greater than the number of historical earthquakes.

Extrapolation of the least-squares exponential function beyond the upper limit of the observed maximum intensity values (VII) yields an unrealistically high value for the number

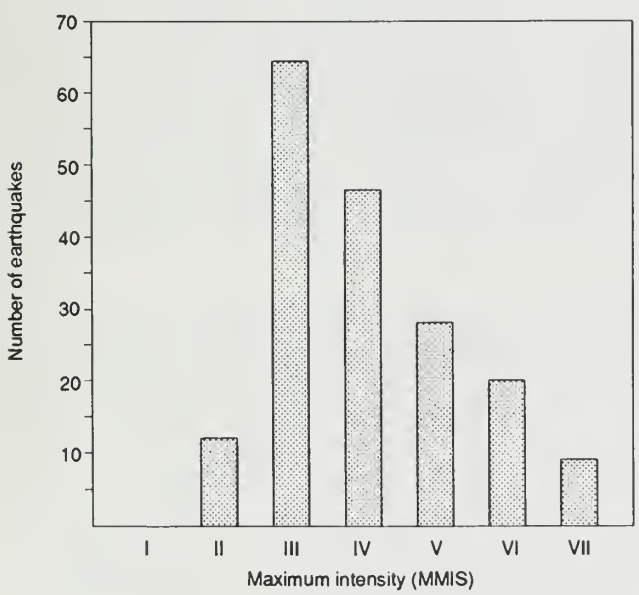

Figure 7 Maximum intensity distribution of historical earthquakes in Illinois.

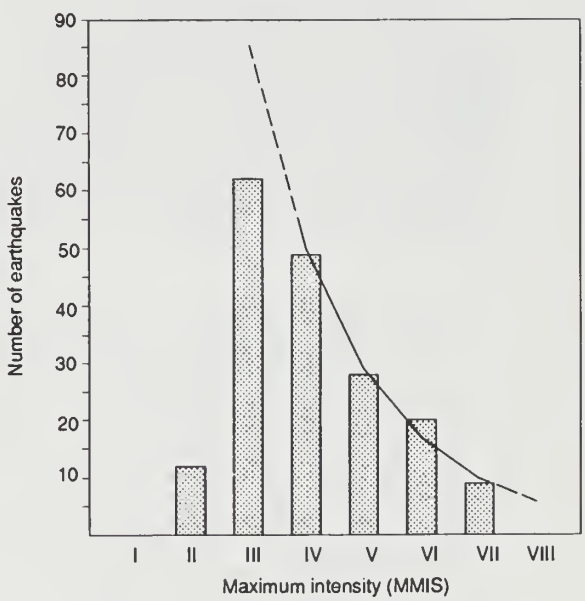

Figure 8 Least-squares exponential function fit to maximum intensity distribution for historical earthquakes in Illinois.

of large earthquakes expected. The extrapolated value for the number of earthquakes with MMIS maximum intensity VIII since 1795 is 5.75. In other words, an earthquake with MMIS maximum intensity VIII is predicted to occur, on the average, every 33.56 years in Illinois. However, no earthquake with maximum intensity VIII has been recorded in Illinois in the past 193 years.

Given the projected recurrence period of 33.56 years for an MMIS maximum intensity VIII earthquake, the *Poisson probability* that no MMIS maximum intensity VIII earthquake would occur from 1795 to the present is 0.00318. Such a low probability seems to indicate that over the span of the historical record the rocks in Illinois have not been able to store enough strain energy to produce an earthquake with MMIS maximum intensity VIII or greater.

SEISMIC RISK

Expectations of damage from future earthquakes are commonly based on (1) historical earthquake records, (2) known zones of weakness in the earth's crust, and (3) the nature of surficial deposits in a region. The third factor usually refers to the localized occurrence of loose, surficial deposits, which in some cases have been known to appreciably enhance seismic intensities.

Seismic risk can be displayed graphically in several ways, but all seismic risk maps divide regions into broad categories based on the kind of damage (intensity) that can be expected. For example, Algermissen (1969) constructed a seismic risk map of the conterminous United States using the following categories: (0) no damage, (1) minor damage, (2) moderate damage, and (3) major damage. The last category is associated with areas for which MMIS maximum intensities equal to or greater than VIII are expected.

If we base our projections of damage only on historical earthquakes having epicenters in Illinois, we conclude that moderate damage can be expected from similar future earthquakes. However, any assessment of seismic risk in Illinois cannot be complete without considering the consequences of future earthquakes occurring elsewhere in the central United States.

The Algermissen (1969) seismic risk map of the United States (figure 9) is based only on historical earthquake records and known zones of weakness in the earth's crust. Nevertheless, it does present the regional seismic risk patterns very well. For the central Mississippi Valley region, the message contained in Algermissen's map is quite clear: the zone of highest seismic risk is related to the New Madrid Seismic Zone (NMSZ). The NMSZ has spawned several damaging historical earthquakes, most notably the catastrophic 1811-1812 New Madrid earthquake sequence and the 1895 earthquake in Charleston, Missouri (Stover et al., 1979b; Stover et al., 1979c).

The devastating sequence of earthquakes that occurred in the NMSZ during the winter of 1811-1812 contained three principal quakes: the first major quake occurred on December 16, 1811, the second on January 23, 1812, and the third on February 7, 1812. The epicenter of the first quake was in Arkansas, and the epicenters of the second and third quakes were in southeastern Missouri. Body-wave magnitudes of 7.2, 7.1, and 7.4, respectively, were assigned to these quakes (Stover et al., 1979b; Stover et al., 1979c; Nuttli, l973b). From newspapers, diaries, and personal accounts, Nuttli (1973b) constructed an intensity map of the December 16, 1811, earthquake (figure 10). If such an earthquake were to occur again, the seismic waves generated would most certainly cause major damage in parts of southern Illinois and would damage structures with poorly anchored foundations in central Illinois. In central and northern Illinois some of the taller structures could also be subject to considerable vibration in response to *resonant* period *surface waves.*

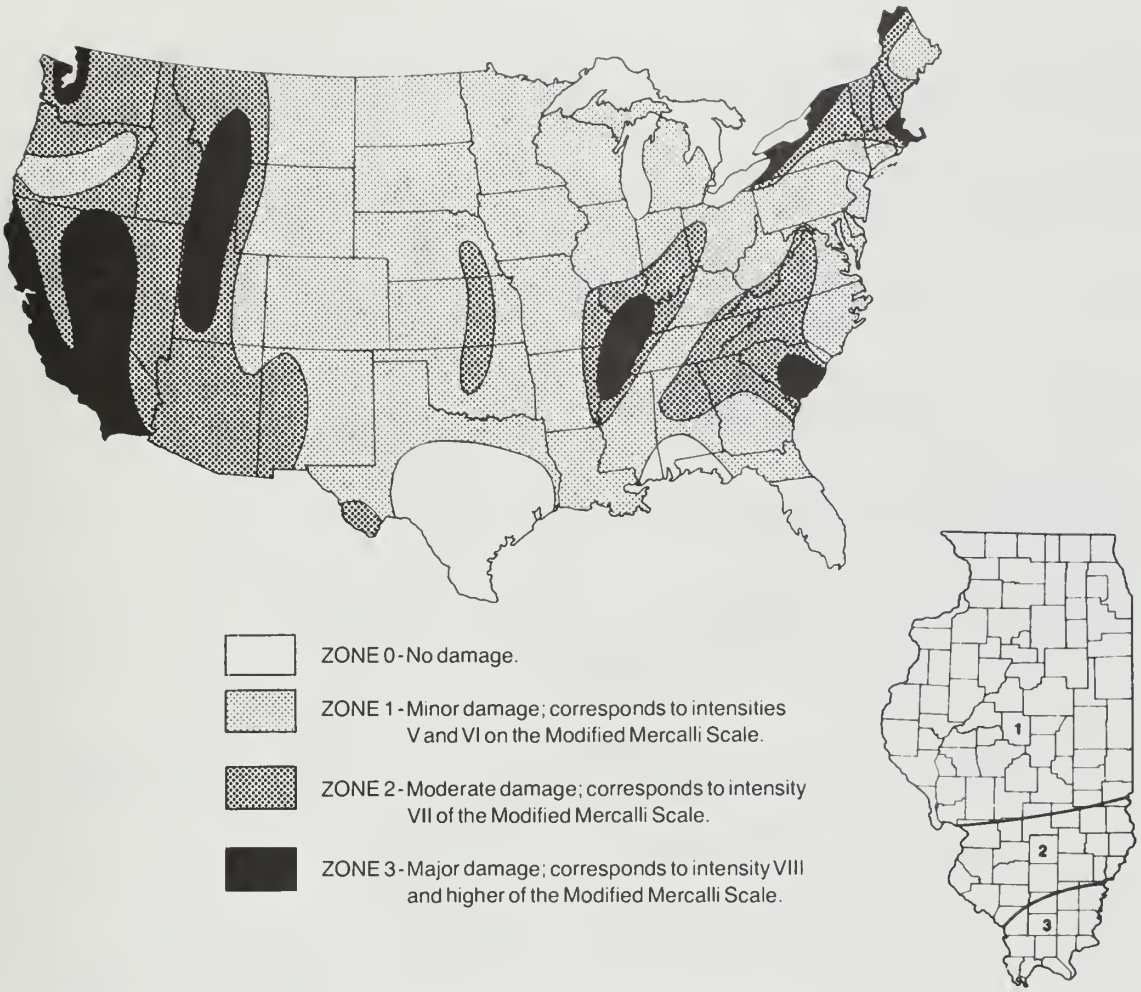
ZONE 0 - No damage.
ZONE 1 - Minor damage; corresponds to intensities V and VI on the Modified Mercalli Scale.
ZONE 2 - Moderate damage; corresponds to intensity VII of the Modified Mercalli Scale.
ZONE 3 - Major damage; corresponds to intensity VIII and higher of the Modified Mercalli Scale.
1
2
3

Figure 9 Seismic risk maps of the conterminous United States and Illinois (Algermissen, 1969).

The Charleston, Missouri, earthquake of October 31, 1895, had an MMIS maximum intensity of IX (Stover et al., 1979b). The epicenter of this earthquake was only 19.5 km (12.1 miles) from Cairo, Illinois, the southernmost city in Illinois. According to the Gupta and Nuttli (1976) relationship for intensity as a function of MMIS maximum intensity and epicentral distance, MMIS intensity values greater than VII would occur as far as 46.4 km (28.7 miles) from the epicenter of such an earthquake. A significant part of southern Illinois would be subject to major damage if another earthquake of the same magnitude should occur in the same area.

Ground motion strong enough to be of concern to the engineer or architect is detected by seismographs as *particle amplitude*, particle velocity, or particle acceleration. Edwards and Northwood (1960) studied the effects of quarry blasts on structures and concluded that particle velocity was the most reliable quantity on which to base damage criteria; they proposed a safe limit of 2.0 in/s (5.08 cm/s) particle velocity. Thoenen and Windes (1942) examined the effects of quarry blasting on structures and recommended an index of damage based on particle acceleration. No damage was expected if accelerations were less than 0.1 g (98 cm/s^2); minor to moderate damage was expected if accelerations were from 0.1 g to 1.0 g (980 cm/s^2); and major damage was expected if accelerations were greater than 1.0 g. Nuttli and Herrmann (1978) developed a relationship for maximum horizontal acceleration as

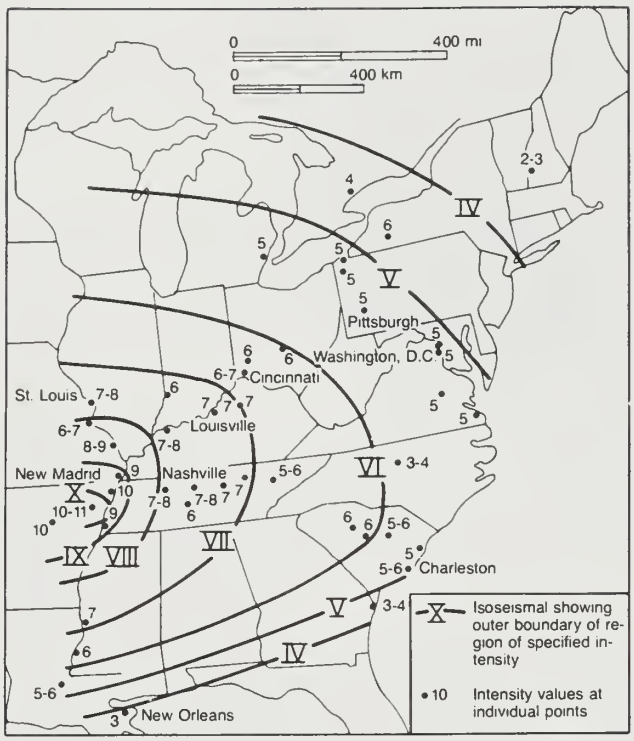

Figure 10 Intensity map of the Mississippi Valley earthquake of December 16, 1811. (Nuttli, 1973b).

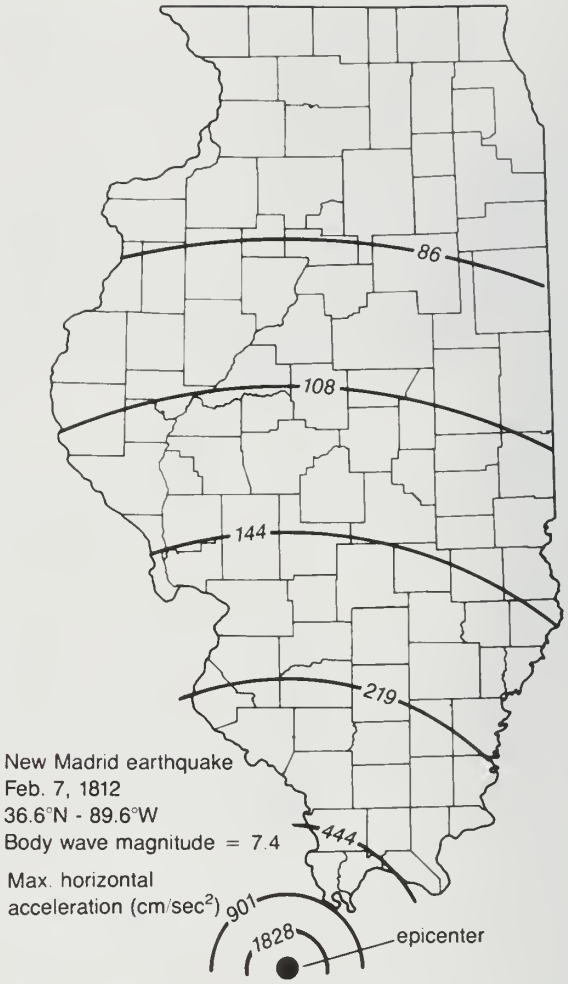

Figure 11 Horizontal acceleration distribution (in the Illinois Mississippi Valley) of the February 7, 1812, New Madrid earthquake.

a function of body-wave magnitude and epicentral distance for earthquakes in the central United States,

$$\log(a_H) = -0.36 + 0.52m_b \qquad R < 15 \text{ km} \quad (3a)$$

$$= 0.84 + 0.52m_b - 1.02 \log(R) \qquad R > 15 \text{ km} \quad (3b)$$

where a_H is maximum horizontal acceleration in cm/s^2;
m_b is body-wave magnitude;
R is epicentral distance in km.

Using this relationship, we calculated the horizontal acceleration distribution that would occur in Illinois if another earthquake of the same body-wave magnitude (7.4) as the February 1812 New Madrid earthquake (figure 11) should occur in the same area. According to the Thoenen and Windes (1942) damage criteria, much of southern Illinois could be expected to experience minor to moderate damage from ground motion if such an event were to recur.

SUMMARY

- The record of historical earthquakes with epicenters in Illinois extends over 193 years and includes 180 quakes.

- Of the historical earthquakes in Illinois, 81.1 percent had epicenters in southern Illinois (below latitude 39.1°N), where known zones of weakness in the earth's crust are more prevalent.

- The cumulative amount of energy released during Illinois earthquakes is relatively small. Far more energy was released during single large earthquakes epicentered in the nearby New Madrid Seismic Zone.

- Historical earthquakes in Illinois have caused only moderate damage; no earthquakes in in the state have had MMIS maximum intensity values as great as VIII.

- The greatest seismic risk in Illinois, especially in southern Illinois, is from large earthquakes that may originate in the New Madrid Seismic Zone.

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GLOSSARY

body wave—a seismic wave that travels through the interior of the earth.

crust—the outermost shell of the earth.

dip-slip fault—a fault in which the relative displacement is along the direction of dip of the fault plane; the offset is either normal (hanging wall moves down dip) or reverse (hanging wall moves up dip).

earthquake—vibrations of the earth caused by the passage of seismic waves radiating from some source of elastic energy.

epicenter—the point of the earth's surface directly above the focus of an earthquake.

exponential function—a function having the form $y = A10^{BX}$ where A and B are constants.

fault—a fracture in rock along which the two sides have been displaced relative to each other parallel to the fracture.

felt earthquake—an earthquake sensed by humans; usually associated with intensities greater than or equal to III on the Modified Mercalli Intensity Scale.

focal depth—the depth of the focus below the earth's surface.

focal mechanism—the orientation of the fault plane and the shearing forces at the focus.

focus—the place within the earth at which an earthquake rupture commences.

intensity—a measure of ground shaking obtained from damage to structures built by humans, changes in the earth's surface, and reports of felt earthquakes. Maximum intensity is also a measure of earthquake size.

listric surface—a curvilinear, usually concave, upward surface of fracture that curves first gently and then more steeply from a horizontal position.

magnitude—a measure of earthquake size, determined by taking the common logarithm of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicenter.

nodal plane—the perpendicular plane, passing through the focus of an earthquake, which defines the quadrantal distribution of compression and dilatation in the first motion of the p-wave phase.

particle amplitude—the amount of displacement of a point on the earth's surface during the passage of seismic waves.

Poisson probability—the probability of an event, governed by the discrete probability distribution $p(x) = \Gamma^{x}e^{-\Gamma}/x!$

recurrence period—the average time interval between earthquakes of a given size.

resonance—induced oscillations of maximum amplitude produced in a physical system when an applied oscillatory stress and the natural oscillatory period of the system are the same.

seismic risk—the relative risk is the comparative earthquake hazard from one site to another; the probabilistic risk is the odds of earthquake occurrence within a given time interval and region.

seismicity—the occurrence of earthquakes in space and time.

seismograph—an instrument for recording as a function of time the motions of the earth's surface that are caused by seismic waves.

steady state—the state or condition of a system or process that does not change in time.

strain—change in the shape or volume of a body as a result of stress, which is force per unit area.

strain energy release—the energy released in seismic waves following fracture of rocks under strain.

strike-slip fault—a fault whose relative displacement is along the direction of the strike of the fault plane, the direction it takes as it intersects the horizontal.

surface wave—a seismic wave that follows the earth's surface only.

zones of crustal weakness—regions in the crust that have undergone considerable past deformation, folding, and faulting.

APPENDIX A. Historical earthquakes having epicenters in Illinois.

Date	Time of origin (UTC)	Latitude (°N)	Longitude (°W)	Focal depth (km)	Body-wave magnitude (m_b)	Maximum intensity (Modified Mercalli)
01 08 1795	9	37.900	89.900			V
08 20 1804	20:10	42.000	87.800			VI
09 17 1819	4	38.100	89.800			IV
09 17 1819		38.100	89.800			IV
11 09 1820	22	37.300	89.500			V
06 09 1838	14:45	38.500	89.000			VII
05 03 1855	3:33	37.000	89.200			IV
05 03 1855	10:0	37.000	89.200			III
05 03 1855	10:5	37.000	89.200			III
10 08 1857	10:0	38.700	89.200			VII
10 08 1857	10:7	38.700	89.200			VII
07 24 1871		37.000	89.200			III
07 25 1871	18:40	38.500	90.000			III
02 08 1872	11:0	37.000	89.200			III
07 09 1874	22:0	37.000	89.200			IV
09 25 1876	6	38.500	87.800			VI
09 25 1876	6:15	38.500	87.700			VI
09 26 1876		38.500	87.800			III
11 19 1877	11:10	37.000	89.200			III
01 09 1878	4:30	37.000	89.200			III
01 09 1878	0	37.000	89.200			III
11 19 1878	11:10	37.000	89.200			III
07 26 1879	17:45	37.000	89.200			III
05 27 1881		41.300	89.100			VI
09 27 1882	10:20	39.000	89.500			VI
10 15 1882	5:50	39.000	89.500			V
10 15 1882	6:30	39.000	89.500			V
10 15 1882	10:35	39.000	89.500			V
10 22 1882	6:10	38.900	89.400			III
01 10 1883	20:25	37.400	89.300			III
01 11 1883	7:12	37.000	89.200			VI
02 04 1883	11	40.500	89.000			III
04 12 1883	8:30	37.000	89.200			VI
07 06 1883	17:15	37.000	89.200			III
11 15 1883	3:14	38.700	90.200			IV
12 27 1885	1:5	40.400	89.000			III
03 18 1886	5:59	37.600	89.200			III
03 18 1886	17:15	37.000	89.200			IV
08 02 1887	18:36	37.000	89.200			V
09 27 1891	4:55	37.000	89.200			V
02 09 1899	5	41.800	87.600			III*
02 09 1899	6:30	41.800	87.600			III*
02 09 1899	9	41.800	87.600			III*
02 09 1899	9:30	41.800	87.600			III*
02 09 1899	12	41.800	87.600			III*

* Values assigned by authors

APPENDIX A *continued*

Date	Time of origin (UTC)	Latitude (°N)	Longitude (°W)	Focal depth (km)	Body-wave magnitude (m_b)	Maximum intensity (Modified Mercalli)
02 09 1903	0:21	37.800	89.300			VI
03 17 1903	11:50	39.100	89.500			III
10 21 1903		38.700	88.100			IV
11 03 1903	18:0	37.800	89.300			III
08 22 1905	10:45	39.900	91.400			III
05 21 1906	19	38.700	88.400			V
11 28 1907	16:30	42.300	89.800			IV
10 28 1908	0:27	37.000	89.200			V
05 26 1909	14:42	42.500	89.000			VII
07 19 1909	4:34	40.200	90.000			VII
08 16 1909	22:45	38.300	90.100			IV
10 22 1909	22:30	41.800	89.700			IV
10 23 1909	9:47	39.000	87.700			V
07 29 1911		41.800	87.600			V
01 02 1912	16:21	41.500	88.500			VI
09 25 1912		42.300	89.100			III
10 17 1913	2:15	41.800	89.700			IV
02 05 1915	6:55	37.700	88.600			IV
02 19 1915	4:35	37.100	89.200			IV
04 15 1915	13:20	38.700	88.100			III
02 18 1916	1:27	37.600	88.800			III
08 24 1916	9	37.000	89.200			IV
04 09 1917	20:52	38.100	90.200			VI
04 09 1917	23:35	38.100	90.200			IV
02 17 1918	8:10	37.000	89.200			III
04 30 1920	15:12	38.600	89.100			IV
05 01 1920	15:15	38.500	89.500			V
05 01 1920	16:9	38.500	89.500			III
02 27 1921	22:16	37.000	89.200			III
09 09 1921	3	38.300	90.100			IV
09 09 1921	5:45	38.300	90.100			III
10 01 1921	9	37.700	88.600			IV
10 09 1921	7:50	38.300	90.100			III
10 09 1921	11:50	38.300	90.100			III
03 22 1922	22:30	37.300	88.900			V
03 23 1922	2:20	37.300	88.900			V
04 11 1922	5	40.900	90.600			II
11 27 1922	3:31	37.800	88.500			VII
03 09 1923	2:45	38.900	89.400			III
05 06 1923	7:50	37.000	89.200			III
05 15 1923	23:42	37.000	89.200			III
11 10 1923	4	40.000	89.900			V
11 29 1923	23:20	37.000	89.200			IV
03 03 1925	16	42.100	87.700			II
07 13 1925		38.800	90.000			V

APPENDIX A *continued*

Date	Time of origin (UTC)	Latitude (°N)	Longitude (°W)	Focal depth (km)	Body-wave magnitude (m_b)	Maximum intensity (Modified Mercalli)
03 22 1926	14:30	37.800	88.600			IV
01 23 1928	9:19	42.000	90.000			IV
02 25 1930	12:45	37.000	89.200			III
07 13 1933	14:42 39.0	37.900	89.900			III
08 04 1933	4:34 15.0	37.900	89.900			IV
10 24 1933		37.300	89.500			III
04 17 1934	13:53 23.0	37.900	89.900			III
05 15 1934	14:28	37.900	89.900			IV
08 20 1934	0:47 27.0	37.000	89.200			VII
08 20 1934	3:37 25.0	37.000	89.200			III
10 30 1934	2:25 47.0	37.500	88.500			IV
11 12 1934	14:45	41.500	90.500			VI
01 05 1935	18:40	41.500	90.600			IV
01 05 1935	18:45	41.500	90.600			III
12 20 1936	22:41 12.0	37.300	89.500			II
06 29 1937	21:45	40.700	89.600			II
08 05 1937	23:12	38.700	90.100			III
11 17 1937	17:04 47.7	38.600	89.100			V
11 23 1939	15:14 51.3	38.200	90.100			V
11 23 1940	21:15	38.200	90.100			VI
11 15 1941	20:4	38.300	90.200			III
11 22 1941	21:55 0.0	37.300	89.500			III
03 01 1942	14:43 6.0	41.200	89.700			IV
03 29 1942	12:43 6.0	37.700	88.600			IV
08 31 1942	9:28	37.000	89.200			IV
03 16 1944		42.000	88.300			IV
07 24 1945	9:0 50.0	37.700	88.200			III*
11 13 1945	8:21	37.000	89.200			IV
02 25 1946	0:52	38.600	89.100			IV
01 16 1947	16:23	37.000	89.200			II
03 16 1947	15:30	42.100	88.300			IV
06 30 1947	4:23 53.0	38.400	90.200			VI
01 06 1948	1:34	38.500	89.100			IV
09 20 1951	2:38 43.0	38.700	89.900			IV
01 07 1952	22:21 5.0	40.200	88.500			III
05 06 1953	7:50	37.000	89.200			III
05 15 1953	23:42	37.000	89.200			III
09 11 1953	18:26 28.0	38.800	90.100			VI
12 30 1953	22	38.600	89.100			IV
04 09 1955	13:1 24.0	38.100	89.800			VI
04 11 1955	10:50	37.700	88.600			II
05 29 1955		38.100	88.900			IV
03 13 1956	15:5	40.500	90.400			IV
01 28 1958	5:56 40.0	37.100	89.200			V
11 08 1958	2:41 43.0	38.400	87.900			VI

APPENDIX A *continued*

Date	Time of origin (UTC)	Latitude (°N)	Longitude (°W)	Focal depth (km)	Body-wave magnitude (m_b)	Maximum intensity (Modified Mercalli)
06 27 1962	1:28 55.7	37.700	88.500	25	5.4	VI
08 14 1965	5:4 30.1	37.100	89.300	5	2.9	III*
08 14 1965	5:46 17.4	37.200	89.300	5	3.2	IV
08 14 1965	5:59 27.0	37.200	89.300		2.5	II*
08 14 1965	13:13 54.1	37.100	89.200	5	3.8	VII
08 15 1965	4:19 1.0	37.200	89.300		3.5	V
08 15 1965	6:7 28.0	37.200	89.300		3.4	V
08 15 1965	11:19 38.0	37.200	89.300		2.7	II*
06 22 1966	11:27 53.0	38.600	88.200	0	3.2	III*
03 31 1968	17:58 9.0	38.000	89.700		3.5	IV*
11 09 1968	17:1 42.0	37.950	88.480	19	5.5	VII
11 09 1968	17:8 17.0	38.000	88.500	0	3.8	IV
11 09 1968	18:45 0.0	38.000	88.500		3.0	III*
11 09 1968		38.000	88.500		3.8	IV*
11 11 1968	11:4 20.0	38.000	88.500		3.0	III*
02 28 1969	13:10 13.1	37.900	88.900		3.2	III*
12 08 1970	23:16	38.000	89.000			III*
02 12 1971	12:44 27.7	38.520	87.900	12	3.3	IV
09 15 1972	5:22 15.7	41.590	89.420	5	4.4	VI
04 18 1973	12:21 53.3	38.470	90.200	15	2.5	II*
03 27 1974	16:10 56.3	38.550	90.130	10	2.4	II
04 03 1974	23:5 2.5	38.590	88.090	11	4.7	VI
06 05 1974	8:6 11.3	38.620	89.940	11	3.6	V
08 22 1974	22:33 59.6	38.230	89.730	12	2.5	IV
03 01 1975	18:12	41.900	88.000			II
06 02 1978	2:7 28.8	38.420	88.460	20	3.5	IV
08 29 1978	7:5 50.3	38.530	88.220	17	2.4	II
12 05 1978	1:48 1.3	38.620	88.360	25	3.5	V
03 13 1980	2:23 13.6	37.930	88.470	19	3.0	III
06 09 1981	14:15 47.8	37.820	89.020	19	3.5	V
08 11 1982	10:32 38.8	37.250	88.730	5	3.0	III
05 15 1983	5:16 22.2	38.738	89.597	9	4.4	VI
08 11 1983	9:33 0.0	37.151	88.726		3.0	III
04 17 1984	4:44 43.8	38.380	88.430	20	3.4	IV
06 29 1984	7:58 29.3	37.710	88.470	2	4.1	V
02 15 1985	15:56 9.9	37.230	89.370		3.3	III
09 09 1985	22:6 31.0	41.850	88.006	5	3.0	V
12 29 1985	5:56 56.7	38.522	88.981	5	3.5	V
08 26 1986	16:41 24.2	38.340	89.790	5	3.7	IV
10 29 1986	5:3 41.3	38.440	89.040	5	2.7	III
06 10 1987	23:48 54.8	38.713	87.954	5	5.1	VI
08 31 1987	17:12 35.5	38.308	89.688	5	3.1	VI
01 05 1988	14:39 17.9	38.742	87.959	5	3.3	IV
03 10 1988	21:24 9.1	37.752	88.835	3	2.6	III
10 05 1988	0:38 52.2	38.690	87.931	5	3.4	IV

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